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RESEARCH MEMORANDUM

LOADS ASSOCIATED WITH SPOILERS AT SUPERSONIC SPEEDS

By Douglas R. Lord and K. R. Czarnecki

Langley Aeronautical Laboratory
Langley Field, Va.

NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

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SUMMARY

The available information concerning the loads associated with spoilers at supersonic speeds has been reviewed and the effect of some of the more important variables in the problem has been considered. Although a large proportion of the data now available are fundamental in nature, they lend considerable basic knowledge to the study of spoiler loadings and permit some estimations to be made.

This paper presents typical data available for various spoiler installations and presents an approximation method for estimating the loadings caused by an unswept spoiler. Some preliminary data and discussion are also presented for spoilers yawed to the main flow.

INTRODUCTION

At the present time there is available only a limited quantity of experimental data concerning the loads associated with spoilers in supersonic flow. During the past few years, however, several tests of a fundamental nature have been made which give some insight into the loadings caused by spoilers and enable a better understanding of the flow phenomena involved. The majority of the data obtained to date are for spoiler installations in what might be termed idealized conditions, and the application of these results to three-dimensional lifting wings with their attendant spanwise variations will undoubtedly introduce new complications. The present results are, however, a vital first step in understanding the flow characteristics and in developing methods for predicting the spoiler loads for an actual installation. The purpose of this paper is to present typical data from some of the most recent tests and to discuss the conclusions which have been reached to date. All data presented are for turbulent boundary layers.

SYMBOLS

M	stream Mach number
M_l	local Mach number [redacted]

p	stream static pressure
p_l	local static pressure
q	stream dynamic pressure
P	pressure coefficient, $\dfrac{p_l - p}{q}$
δ_{SEP}	effective angle of flow separation ahead of spoiler
l	horizontal distance from top of spoiler to point of flow separation
h	spoiler height
Λ	sweep angle
D	spoiler section drag
c_d	spoiler section drag coefficient, D/qh
H	spoiler section moment about base of spoiler
c_h	spoiler section hinge-moment coefficient, H/qh^2

MODELS AND TESTS

Figure 1 illustrates the testing techniques which have been used in studying this problem. Although some of the tests were initiated as part of shock—boundary-layer interaction programs, they are inherently suited for studying the loadings ahead of spoilers. On each of the sketches shown, the horizontal lines above and below the diagram define the location of the tunnel walls. In the upper left sketch of the figure, the two-dimensional step technique, used both at the David Taylor Model Basin (ref. 1) and at Princeton University (ref. 2), is shown. Orifices ahead of and on the front face of the spoiler were used to determine the loadings.

The collar-on-a-tube technique, illustrated in the top middle sketch of figure 1, was employed in tests in a blowdown jet of the Langley Gas Dynamics Branch (ref. 3). Here again, a single row of orifices was used to obtain pressures along the tube and on the front face of the collar.

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Tests were made in the Langley 9-inch supersonic tunnel (ref. 4) on a two-dimensional airfoil (as shown in the upper right sketch of fig. 1) in which spoilers of various heights were mounted at three chordwise locations on the airfoil upper surface. A single row of orifices along the surface measured the pressures both ahead of and behind the spoiler.

The three techniques shown so far have been used primarily to study the effect of spoilers placed normal to the flow. In order to study the loadings caused by a spoiler in the yawed condition such as would be encountered on a swept-wing spoiler installation, with the simplifying condition of uniform flow ahead of the spoiler, the technique shown in the lower left sketch of figure 1 was used in the Langley 4- by 4-foot supersonic pressure tunnel. Spoilers of varying height, span, and deflection angle were mounted on a turntable in a flat boundary-layer bypass plate. The turntable was instrumented with approximately 260 orifices located so that, as the turntable was rotated to obtain various sweep angles, rows of orifices were always so alined as to give detailed pressure distributions in the streamwise direction. Pressures were obtained ahead of and behind the spoilers as well as on the front and rear faces of the spoiler itself.

In the lower right-hand corner of figure 1 is a plan view of the three-dimensional semispan-wing model which was tested in the 4- by 4-foot supersonic pressure tunnel with various spoiler installations. A typical location for a full-span spoiler is shown, in addition to the five rows of orifices located across the wing span. Some of the variables investigated in these tests were spoiler height, span, chordwise location, and sweep.

DISCUSSION

Unswept Spoilers

In figure 2 the typical loadings caused by an unswept spoiler in supersonic flow are illustrated. In the left part of the figure the pressure distributions ahead of and behind three spoilers have been superimposed. Two of the spoilers were vertical spoilers of different heights and the third was a flap-type spoiler deflected 45° to the surface. As has been previously demonstrated at subsonic speeds, when the loadings are plotted as a function of distance from the top of the spoiler in terms of the actual spoiler height above the surface, the loadings are nearly identical. Further investigations have shown that this remains true with reductions in spoiler height until the height becomes of the same order of magnitude as the boundary-layer thickness.

Since it was found that, at this Mach number, the spoiler caused the flow to separate approximately $5\frac{1}{2}$ spoiler heights ahead of the spoiler top, a simple approximation to the loading can be obtained, as shown, by following these rules: First, drawing a line from the separation point to the top of the spoiler determines the angle through which the flow must turn and, therefore, the average pressure in the forward dead-air region can be calculated. Further, from examining the pressure distributions, it appears that at the spoiler top the flow expands through an angle approximately three times the value of the separation angle just determined. By calculation then, it is possible to get the pressure immediately downstream of the spoiler. It would ordinarily be anticipated that this pressure would remain constant until the flow impinged on the surface and again had to be turned to realine with the stream. Experience has shown, however, that the compression takes place in a gradual manner and is approximately completed at a point downstream of the spoiler the same distance as the separation occurred upstream. A straight line connecting the last computed pressure point with the proper distance along the axis in the downstream direction, therefore, completed the approximation.

On the right-hand side of figure 2 are shown the loadings on the front and rear faces of the three spoilers depicted. The vertical spoilers exhibit marked pressure increases on the front face near the bottom and top of the spoiler which indicate stagnation of the local flow at these points. The 45° spoiler has its highest pressure at about 80 percent of its height, followed by a rapid expansion. These variations are caused by the circulatory flow in the dead-air region ahead of the spoiler. On the rear faces of the spoilers, there appears to be little effect of spoiler height or deflection angle, and indications of any circulation are lacking. At the present time, no technique has been obtained for estimating the distribution of pressures along the front face of a spoiler; however, the uniform pressure on the rear face may be approximated by using the pressure obtained just after the expansion of the main flow at the spoiler top.

If the experimental pressures are known on the wing surface immediately ahead of and behind the spoiler, a good approximation of the average loads on the spoiler can be obtained by assuming that these pressures apply uniformly over the adjacent spoiler faces.

Since, in the discussion of the technique used in estimating the loadings caused by a spoiler, it was necessary to first know the extent of the separated region, the obvious question which follows is how to determine this distance. In figure 3 the separation distance from the spoiler in terms of the height is plotted against Mach number. All the data on this figure were determined from the tests discussed in figure 1. The two-dimensional results are shown as symbols, whereas the results from the only available three-dimensional tests are shown as a shaded area.

The data for any one family of test points in which there was a Mach number variation indicate a decreasing trend with Mach number. From consideration of the scatter of the available results, it appears that the assumption of a constant separation distance of $5\frac{1}{2}$ spoiler heights as shown by the dashed line would be satisfactory for estimating loadings in the Mach number range from 1.6 to 3.0.

Effects of Sweep

Up to now, only unswept spoilers have been discussed. Figure 4 illustrates the changes in upstream influence of a spoiler caused by increasing the spoiler sweep from 0° to 60°. In considering the effects of spoiler sweep, a new phenomenon is involved: The flow not only must be deflected by a shock from the surface to surmount the spoiler height, but a new shock is necessary to turn the flow along the surface - thus allowing the flow to move parallel to the face of the spoiler.

It can be seen from figure 4 that, for an unswept spoiler, there is relatively little effect of the spoiler tips on the upstream influence of the spoiler within its spanwise boundaries. As the spoiler is swept, the curve of initial disturbance assumes the position of a detached shock about the upstream tip of the spoiler.

This interaction is illustrated better in figure 5, in which the effect of 45° sweep on the pressure distributions in streamwise rows at two stations along the spoiler span is shown. The upper diagrams show the loadings ahead of, behind, and on the spoiler at station 1; whereas the lower diagrams show the same variations at a station considerably closer to the spoiler tip. At 0° sweep, the loadings are almost identical at the two stations shown. When the sweep is increased to 45°, the compression ahead of the spoiler occurs in two steps and is separated by an expansion region. At station 1, the change in sweep from 0° to 45° increases considerably the upstream influence of the spoiler. At station 2, nearer the tip, the initial compression occurs much closer to the spoiler than it does at station 1; however, the peak of the expansion region appears to be about the same distance from the spoiler at both stations. The final compression ahead of the spoiler is much greater at station 2 and is also illustrated by the higher pressure along the front face of the spoiler at this station. The pressures in the region downstream of the spoiler are generally more negative at station 2 for this sweep condition.

Since the variation in loading along the span has been shown, it follows that the integrated lift and pitching moment caused by the spoiler will also vary spanwise. Because of the limited number of stations across the span and the relatively low spoiler span-to-height ratio for these

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tests, it is impossible to give a complete picture of the spanwise variations of lift and pitching moment caused by a swept spoiler. Indications are, however, that when a spoiler having a sweep of 45° or greater is used, there is a strong tendency for reversal in lift and reduction in pitching moment within approximately 10 spoiler heights of the upstream tip. These indications have been borne out by correlations obtained between data from these tests and data from three-dimensional tests in the Langley 16-foot transonic tunnel (ref. 5) on a 45° swept-wing—spoiler combination in which the local wind velocities ahead of the spoiler were supersonic.

In accordance with the discussion of the effects of spanwise location on the changes with sweep, figure 6 shows the variations in spoiler section drag and flap-type spoiler section hinge-moment coefficients along the span for various angles of sweep. At 0° sweep, the drag and hinge moments are constant along the span insofar as was investigated. As the spoiler is swept to 60°, the drag and hinge moment first fall off on the downstream portion of the spoiler and then fall off all along the span.

CONCLUDING REMARKS

Considerable information of a fundamental nature is now available on the status of research on loadings caused by spoilers at supersonic speeds. Estimations can be made very simply to determine the loadings caused by unswept spoilers in uniform flow fields. The effects of sweep, though understood somewhat, are still too complex to permit any simple approximation techniques to be demonstrated. It is anticipated that further analysis of the available information should clarify this problem; however, detailed loading investigations of spoiler installations on three-dimensional lifting wings will be needed for a complete solution to the problem.

Langley Aeronautical Laboratory,
National Advisory Committee for Aeronautics,
Langley Field, Va., April 21, 1955.

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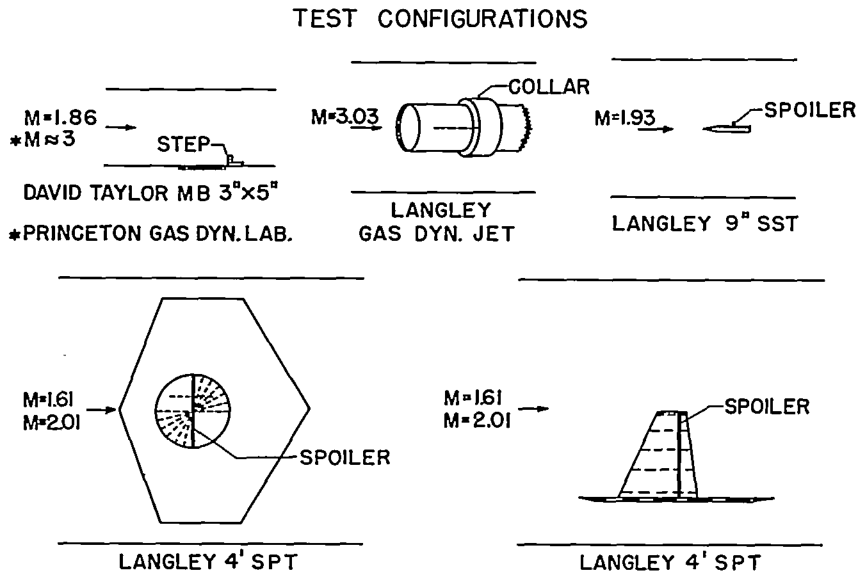

Figure 1

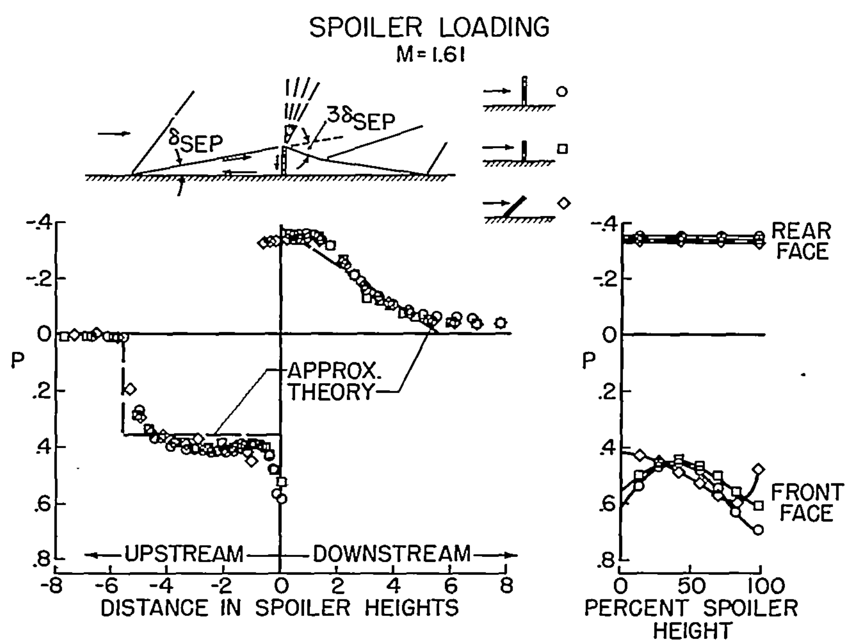

Figure 2

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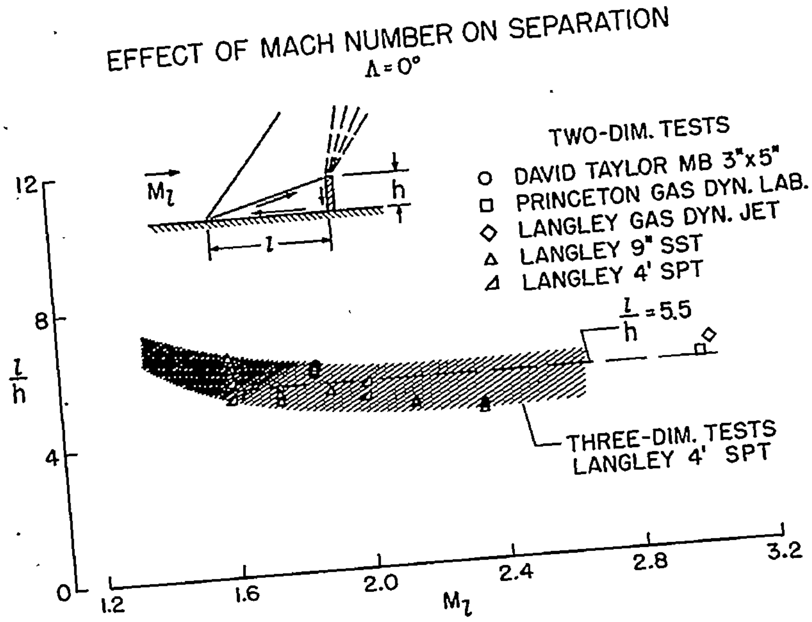

Figure 3

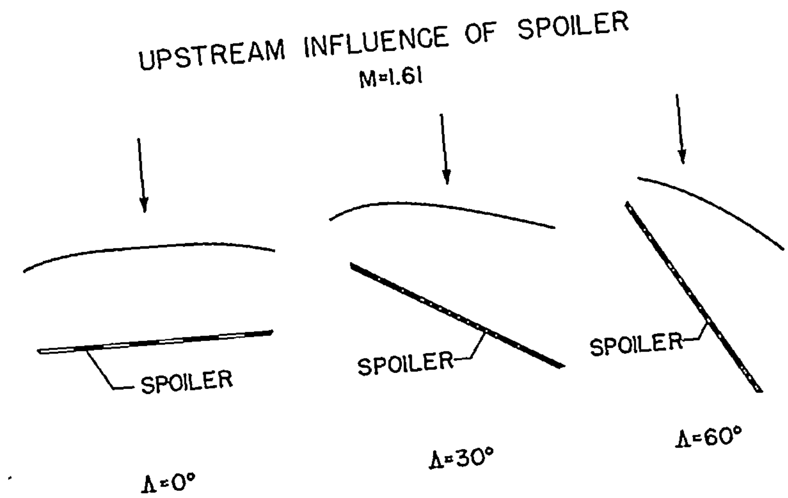

Figure 4

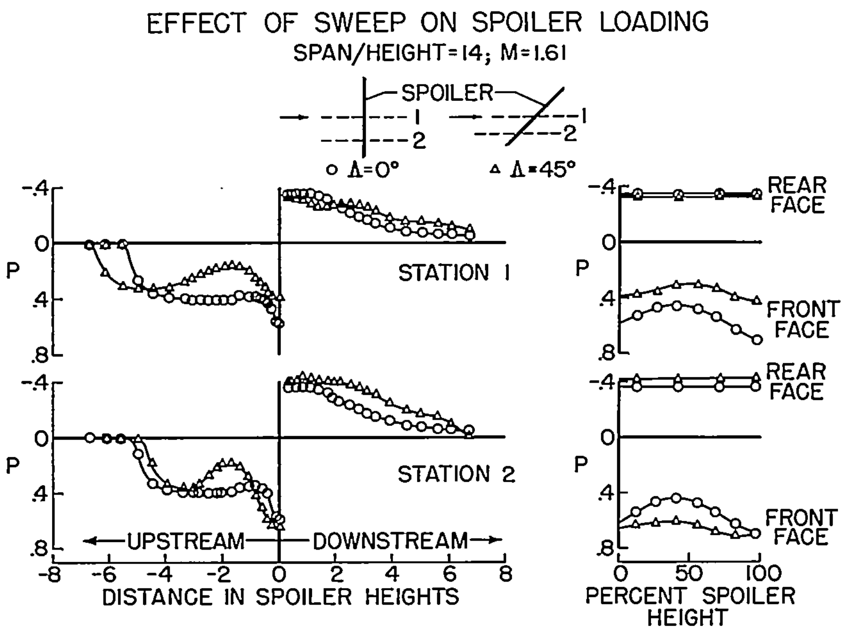

Figure 5

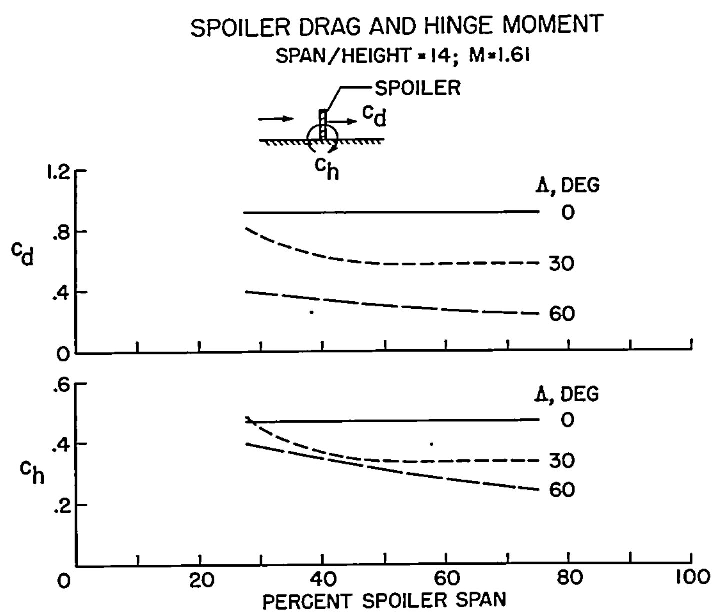

Figure 6